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A Pilot Study to Rate Determinants of Exposure from Videotaped Work Activities of Farmers' Use of Pesticides

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Industrial hygienists often observe workers to determine who should be measured based on a predicted exposure level. Such evaluations are usually based on real-time observation, yet surprisingly little research has been conducted on what determinants of exposure industrial hygienists use to rank workers and whether the ranking is accurate. Accuracy of the ranking may also be affected by the observation process, which is limited when conditions in the workers' immediate environment are rapidly changing. An alternative to real-time observation is videotaping workers and evaluating the tapes at a later date.

A pilot study was conducted using previously collected data to determine if workers could be ranked by exposure level utilizing a scoring system to rate videotaped work practices. Six farmers had been videotaped and their dermal exposures measured as they applied insecticide to hogs. In this study, scores were developed to rate the farmers' working conditions by exposure level. Two types of determinants were used to describe exposure: touching and work practices. Touching included the number of times parts of the body had contact with surfaces possibly contaminated with insecticide. Work practices included the types of clothing and protective equipment worn as well as specific practices used by the farmer (e.g., application method). Two raters conducted independent assessments of the videotape using the same criteria. One rater reviewed the tape twice. Agreement between the raters for the "touching" score was weak (intraclass coefficient (ICC) = 0.28), but there was excellent agreement between the two raters (ICC = 0.92) for overall quality of work practices. As expected, a greater number of touches was moderately correlated with an increase in total exposure ($r_s = 0.60$) and there was a weak inverse relationship between protective work practices and the exposure under the clothing ($r_s = -0.26$). All other relationships with exposure level were contrary to what was expected. Since videotapes provide the industrial hygienist with a record of work events and can capture details that might otherwise be missed or not considered they may play a useful role in exposure assessment, especially if carefully developed procedures are followed to overcome the limitations found by this pilot study.

Keywords Exposure Assessment, Determinants of Exposure, Work Practices, Videotape

Exposure assessment, a crucial component of protecting workers, is typically done by measuring exposure levels. Industrial hygienists often observe workers to determine who should be measured based on an estimated exposure level. Due to the emphasis on compliance with federal and state occupational exposure levels, the most highly exposed workers are generally selected for measurement. These evaluations are usually made based on real-time observation of workers by industrial hygienists, yet surprisingly little research has been conducted on what determinants of exposure industrial hygienists use to rank workers and whether the ranking is accurate. Since real-time observation may be limited by rapidly changing conditions in the workers' environment, it may also affect the accuracy of the ranking. An alternative to real-time observation is videotaping workers and evaluating the tapes at a later date.

To investigate the ability of industrial hygienists to rank workers by exposure level by observation of a videotape, we took advantage of data collected from a previous study[1–4] in which dermal exposures to farmers were measured as they applied insecticides to hogs. The farmers were also videotaped to increase the investigators' understanding of the measurements. Using the videotape we evaluated possible determinants of exposure to rank the farmers by exposure level and compared those rankings with the rankings from the measurement data.

METHODS

As part of a methodological study that investigated exposure assessment techniques, 10 hog farmers, who apply insecticides to their hogs in the normal course of their work, were measured for phosmet (an insecticide) exposure over one application.[1–4] The number of hogs treated ranged from 62 to 214 hogs per farmer. Exposure methods from the original study have been described in detail elsewhere.[4] Briefly, nine patches were attached onto, and nine patches were attached under, the farmers' normal clothing to measure their dermal exposures while they applied phosmet to hogs. The farmers were also provided with cotton gloves that served as the measurement device for hand exposures. The patches and gloves were worn for the duration of the application process.

Of the 10 farmers originally measured, 7 farmers were arbitrarily videotaped during one spray episode. All farmers were included on a single videotape. One of these farmers was not included in this study because corresponding exposure information was not available. Because the farmers in the original study had been videotaped during application to enhance understanding of the measured exposures, the process was not taped for the duration of the application period, but rather at critical points when something interesting was occurring.

Two authors of this study observed the videotape to develop a checklist of determinants that could affect exposures. Definitions were assigned to each determinant on the checklist and were agreed upon by two raters. The two authors (raters) reviewed the videotape independently of each other and recorded their observations on the checklist. To test the intra-rater reliability of this method, the first rater (Rater 1a) repeated the review seven weeks after the first observations were made (Rater 1b). Results of the exposure measurements were not made available to Rater 1 until after the second review of the video was completed. The second rater (Rater 2) did not see the videotape prior to this study and although she had previously analyzed the measurement data, it occurred about one year before the start of the current study. For these reasons it was felt that this rater's review would not be biased. Although only two raters (Rater 1 and Rater 2) reviewed the videotape, in this study the two evaluations by Rater 1 will be described as though separate raters performed them.

Two types of determinants were used to characterize exposure during the application process: touching, and work practices (Table I). For touching, two components were developed: ever touched, and total number of touches. Scores were assigned based upon hand and leg/foot contacts with insecticide-contaminated surfaces or the insecticide solution. The number of touches was normalized by the videotaped time to give number of touches per hour. Work practices were represented by two components: specific work practices used by the farmer, and level of protection. Scores were assigned based upon the protection provided by the specific work practice or type of personal protective equipment or clothing worn. A summary score of these, called overall quality of work practices, was also calculated.

The scores for all determinants were compared to various exposure metrics. The total mass of accumulated phosmet on all patches that were worn on top of the clothing was summed for the outer exposure level. Similarly, an inner exposure level was based on the sum of the phosmet mass on the patches worn under the clothing. Hand exposure was derived from the mass of phosmet on the gloves (gloves were considered a surrogate for what would have been received on the hands had gloves not been worn). The concentrations received on the gloves and the inner patches were summed to derive a total exposure level. The mass for each of these metrics was divided by the total time (transport, mixing, application, and cleanup) to derive hourly exposure rates for each farmer.

To evaluate the reliability of the raters' measurements, the intra-class correlation coefficient (ICC) was used.[5] Comparisons were made between Rater 1a and 1b to estimate intra-rater reliability. To estimate inter-rater reliability, comparisons were made between Rater 1a and Rater 2. Additionally, means for Rater 1a and 1b were calculated for each type of score and compared to the corresponding scores of Rater 2. Because the normality assumption for the Pearson correlation coefficient could not be verified due to the small sample size ($n = 6$), the Spearman rank correlation coefficient (r_s),[5] a nonparametric method, was used to evaluate the association between the exposure determinant scores and the measured phosmet exposure levels. A mean score for all three raters was calculated to compare with the exposure measurements.

RESULTS

The mean duration of the farmers' application process was 60 minutes (standard deviation [SD] = 0.55), while the mean duration of their videotaped activity was approximately 20 minutes (SD = 0.20). Hourly exposure rates for the farmers ranged from 13.0–676.7 μg/hr for outer exposure, 0.9–132.5 μg/hr for inner exposure, 38.3–7,441.8 μg/hr for hand exposure, and 43.8–7,442.8 μg/hr for total exposure.

Reliability

There was excellent agreement between the scores of Raters 1a and 1b for all variables (Raters 1a and 1b, ICC = 0.88 to 0.97); and between the two raters (Raters 1a and Rater 2) for ever touched (ICC = 0.92) (Table II). There was moderate agreement between scores of the raters for number of hand touches (ICC = 0.36) but the relationships were weaker for total number of touches and leg/foot touches. There was, however, excellent agreement between the raters (ICC = 0.87 to 0.92) for overall quality of work practices and its components, specific work practices, and level of protection. Due to the high correlation between Rater 1's two sets of scores, comparisons between the mean of Rater 1a and 1b's scores with Rater 2's corresponding scores were similar to those described above and are therefore not presented.

Validity

There was no clear pattern between the raters' scores for the different work practices and the measured exposure levels (Table III). There was a moderate relationship ($r_s = 0.37$)

TABLE I
Assignment of scores for the determinants of exposure

Determinant[A]	Score assignment (point value)
Touching	
Ever touched	Each surface possibly contaminated with insecticide or the actual insecticide solution if hands, legs/feet ever contacted it (1).[B] No contact (0).
Total number of touches[C]	Sum of scores for hand and leg/foot touches.
Total number of leg/foot touches	Each leg/foot contact with a surface possibly contaminated with insecticide or the insecticide solution (1).[B]
Total number of hand touches	Each hand contact with a surface possibly contaminated with insecticide or the insecticide solution (1).[B]
Work practices[D]	
Overall quality of work practices	Score created by summing the scores for specific work practices and level of protection.
Specific work practices	Mixing raw materials (0); Not mixing raw materials (1).
	Dragging the spray hose through an area of contamination (0); Not dragging the spray hose through an area of contamination (1).
	Adjusting equipment during application (0); Not adjusting equipment during application (1).
	Application inside a building or partially enclosed area (0); Application outside a building or partially enclosed area (1).
	Spraying above waist level (0); Spraying at waist level (1).
	Spraying with an up/down motion (0); Not spraying with an up/down motion (1).
	Spraying with a side-to-side motion (0); Not spraying with a side-to-side motion (1).
	Spraying above the shoulder (0); Not spraying above the shoulder (1).
	High-pressure spray (0); Low-pressure spray (1); Pour-on application (2).
Level of protection	Sum of points for individual items worn as listed below.
Gloves	No Gloves (0); Cotton gloves (1); Rubber gloves (2).
Respirator	No respirator (0); Wear respirator (1).
Type of clothing	Short-sleeved shirt (0); Long-sleeved shirt (1).
	No jacket (0); Jacket (1).
	Long pants (0); Overalls (1).
	No apron (0); Apron (1).
	Leather shoes (0); Rubber boots (1).
	No glasses (0); Glasses (1).
	No cap (0); Cap (1).

[A] A mean score for each determinant was calculated across all farmers for each rater.
[B] Surfaces possibly contaminated with insecticide included personal protective equipment or clothing worn; the face and brow; the hogs; the spray hose or fence; and the wand or jug used to apply insecticide.
[C] The number of touches was normalized by the taped time to give number of touches per hour.
[D] More protective work practices, personal protective equipment, and clothing received higher scores.

between ever touched a possibly contaminated surface and outer exposure ($r_s = 0.37$) but no relationships were observed with inner, hand, or total exposures ($r_s = -0.09$ to -0.23). The total number of touches was moderately related to outer exposure ($r_s = 0.37$) and total exposure ($r_s = 0.60$) but was inversely related to inner exposure ($r_s = -0.43$). The total number of hand touches was moderately related to hand exposure ($r_s = 0.31$), but related poorly or not at all to outer, inner, and total exposure.

As the level of protection increased, the inner exposure decreased but the relationship was weak ($r_s = -0.26$). All other observed relationships between exposures and work practices were contrary to what was expected. Overall quality of work practices that were considered protective and specific work practices that were considered protective were moderately related with increases, not decreases, in outer exposure ($r_s = 0.43$ and $r_s = 0.43$, respectively) and total exposure ($r_s = 0.54$ and

TABLE II
Intra-class correlation coefficient (ICC) among raters' scores for determinants of exposure (reliability)

Determinant	ICC (Raters 1a and 1b)	ICC (Raters 1a and 2)
Touching		
Ever touched[A]	0.91	0.92
Total number of touches[B]	0.88	0.28
Total number of hand touches	0.88	0.36
Total number of leg/foot touches	0.97	0.17
Work practices		
Overall quality of work practices	0.89	0.92
Specific work practices	0.92	0.87
Level of protection	0.96	0.92

[A]Includes hands, legs, and feet.
[B]Total number of touches includes number of hand, leg, and foot touches.

$r_s = 0.54$, respectively). More protective work practices (overall quality of work practices, specific work practices, level of protection) were also related with higher, rather than lower, hand exposures, although these relationships were weak to moderate ($r_s = 0.14$–0.37). In addition, as the level of protection increased, outer exposure increased ($r_s = 0.82$).

DISCUSSION AND RECOMMENDATIONS

It is generally thought that industrial hygienists can observe workers and rank them by exposures in the general sense of identifying lower- and higher-exposed workers. A number of factors must be considered during the observation, but many of these may be of short duration and missed. Use of a videotape may increase the ability of the industrial hygienist to accurately identify and rank exposed workers. When evaluating workers' exposures, a number of factors must be considered, including the mechanism of release of a substance into the air, effectiveness of engineering controls, and work practices. Proper selection of the workers to be evaluated is crucial to the accuracy of the interpretation of measurement, yet little is known about how such a selection is made and whether or not that selection results in the proper workers being evaluated. Using previously collected data we evaluated whether a systematic review of videotaped insecticide applications might be helpful to rank farmers' exposures.

TABLE III
Spearman rank correlation coefficients (r_s) for determinants of exposure scores and farmers' phosmet exposure levels (validity)

Determinants	Outer exposure	Inner exposure	Hand	Total (inner + hand)
Touching[A,B]				
Ever touched[C]	0.37	−0.09	−0.14	−0.23
Total number of touches[C]	0.37	−0.43	–[E]	0.60
Raters 1a and 1b	−0.37	−0.83	–[E]	0.14
Rater 2	0.49	−0.20	–[E]	0.54
Total number of hand touches	0.14	0.26	0.31	0.09
Raters 1a and 1b	−0.31	0.14	0.66	0.54
Rater 2	0.37	0.09	0.31	0.09
Work practices[B,D]				
Overall quality of work practices	0.43	−0.03	0.37	0.54
Specific work practices	0.43	−0.03	0.26	0.54
Level of protection	0.82	−0.26	0.14	0.09

[A]A positive value indicates that as touching scores increase, exposure levels increase.
[B]Calculations performed using average scores for all three raters unless otherwise indicated.
[C]Includes hands, legs, and feet.
[D]A negative value indicates that as work practices become more protective, exposure levels decrease.
[E]A correlation was not performed since total number of touches included hand, leg, and foot touches.

We investigated two main aspects to evaluate the relationship between determinants and exposure. The first was the reliability or reproducibility between raters. We found that an observational checklist identifying determinants of exposure can be reliable, but that care must be taken to ensure that definitions for all determinants are clearly understood by the users. There was excellent agreement both within and between the raters for easily defined and observable work practices (e.g., type of clothing worn). However, for determinants that were not as easily defined or observed (e.g., number of touches) the raters in this study had a more difficult time agreeing. Agreement between the raters was low to moderate for the number of hand and leg/foot touches, as well as total number of touches (Rater 1a, N = 284; Rater 1b, N = 295; and Rater 2, N = 529). In spite of agreed-upon definitions prior to the evaluation of the farmers, after the evaluation was completed the raters discovered that they had interpreted the definition for touching differently. When the farmers' hands or legs/feet were hidden from view, Rater 1 did not count any touches. However, in the same instance, when Rater 2 was able to have a partial view of a farmer's arm or leg/foot on the video making a movement that appeared to indicate touching (such as a hose moving), Rater 2 assumed that touching had occurred and counted a touch. Other investigators have found that raters have difficulty agreeing, especially with regard to touching.[6] Practice sessions and more precise definitions should help to reduce these types of differences.[6–17] It has also been suggested that in order to improve reliability one might increase the calibration of the raters by enhancement of the training process or utilize statistical modeling to account for differences.[17] In this study, because of the small number of farmers videotaped, such approaches were not possible.

The second component evaluated in this study was validity (i.e., how well the evaluation reflected the measured exposure). To ensure validity, investigators must properly identify the important determinants of exposure, give them the appropriate weights to ensure that exposure hazards are accurately reflected, and correctly observe them in the workplace. Our ability to do these was inconsistent. Similar to earlier findings from these data,[4] we found that, as level of protection increased, inner exposure decreased ($r_s = -0.26$), but this relationship was not very strong. We also saw a positive relationship between total number of touches and exposure levels ($r_s = 0.60$). However, this result is inconclusive because there was not good agreement between the raters for touches. In contrast we found moderate to strong relationships between outer and total exposure, and those determinants that were found to be reliable (overall quality of work practices, specific work practices, and level of protection), although these relationships did not reflect what was expected. Instead of a decrease in exposure levels with more protective work practices, an increase was observed.

The small sample size (n = 6) and number of raters (n = 3) in this study might have masked our ability to clearly observe the relationship between exposure level and determinants. For example, because of the small sample size, when we evaluated specific work practices we evaluated all farmers together, regardless of application method (e.g., low-pressure spray, high-pressure spray, and pour on). We attempted to account for possible differences between these application methods by assigning different scores to them but the scores may have been inappropriate. Had the number of farmers been greater we could have grouped the farmers according to application method.

The lack of validity suggests that we did not identify the correct exposure determinants or that we did not assign the proper weights to our scores. The industrial hygiene field has only recently started focusing on determinants of exposure.[18–19] Few studies have evaluated pesticide exposures of animal farmers and so we could not use the literature to identify either the determinants or the weights. Had there been more farmers in the evaluation, a subset could have been selected for identifying the determinants and estimating the weights for the remaining group.[20] It is also possible that we had correctly identified the determinants and their weights but the limitations of the videotape contributed to our difficulties.

The videotape was designed to enhance general understanding of the application process rather than the farmers' behaviors and how they related to exposure levels. For example, because the farmers were very mobile during application of the insecticide, there were instances when the camera did not follow them and they were hidden from view. In addition, the videotape did not record approximately two-thirds of potential exposure time (application period $\bar{x} = 60$ minutes, taping period $\bar{x} = 20.4$ minutes). It is not clear to what extent our evaluations were biased, or in which direction they were biased, by these limitations. The ability to observe and properly rate the relationship between behavior and exposure levels could be improved in future studies by ensuring that during videotaping the subject is followed at all times, especially when mobile, and that the recording time of the video includes the entire exposure monitoring period.

This research suggests that the use of "video exposure monitoring" might help to improve the ability of researchers to identify exposure determinants and correlate behavior and exposure levels. In this technique, measurements from real-time monitoring devices are displayed directly on the video image to allow simultaneous viewing of a worker's behavior and corresponding exposure levels. This technique has been used previously to assist in the reduction of personal exposures in hazardous work environments[21] but it would be extremely useful to apply this technique to exposure assessment, especially in the evaluation of the relationship between work practices and exposure levels.

Although there were drawbacks as noted above, there are several reasons why we believe that videotapes could play an important role in exposure assessment, especially if carefully developed procedures are followed. Not only does a videotape provide the industrial hygienist with a record of work events, but it also captures details that industrial hygienists might not otherwise perceive or remember and provides a visual reference for others to review if measurement data are questioned. It may also allow the viewer to identify possible determinants of exposure, including behavior. The identification of behavior-related items in epidemiological studies could explain outliers and unexpected variations in disease risk of individuals.[22] Finally, careful review of the videotape could assist in determining the point in a process where engineering controls might be instituted to control exposures.

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